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LUNAR-CORRELATED VARIATIONS IN WATER UPTAKE BY BEAN SEEDS [1]

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Water uptake in pinto beans, *Phaseolus vulgaris*, was chosen as a simple process by which to assay responses to natural atmospheric and laboratory related variations in extremely weak electromagnetic fields.

A previous study (Brown and Chow, 1973) had disclosed that the mean water uptakes of two presumably independent groups of 20-bean samples at separated sites in the laboratory could display day-to-day variations of an extent and character unaccountable in terms of any known environmental variations while exhibiting a coefficient of correlation between them greater than + 0.8. Correlation between two closely adjacent bean samples could be influenced by very slow rotation, 6 rpm, of the pair with the influence differing between clockwise and counterclockwise rotation. Two populations of 20-bean samples simultaneously investigated at two different laboratory sites could, under some special conditions, exhibit between them a strong *negative* correlation in their day-to-day varying water uptake rates. It was postulated (Brown and Chow, 1973) that the beans in their water uptake were able to correlate either positively or negatively with variations in whatever was one of the chief subtle environmental parameters effecting the day-to-day fluctuations, and that other subtle environmental influences could bias the determination of sign.

In the course of further search for characteristics of the fluctuations in the subtle environmental parameters influencing water uptake and apparent interactions among adjacent experimental samples, it was discovered that the water uptake in beans was apparently exhibiting a mean synodic monthly variation. This was noted for a number of experimental series which were initially designed to learn the effects of different numbers and spatial configurations in clusters of vessels, containing beans, upon mutual interactions among them, as well as to extend our knowledge of characteristics of influences of clockwise and counterclockwise rotations and of unstable horizontal magnetic vectors upon interactions among closely adjacent groups of beans.

Materials and Methods

Several hundred-pound bags of beans were obtained and stored in the laboratory which was air-conditioned to relatively uniform temperature throughout the year. For the observations reported here the beans were taken from the bags without selection, other than discarding the occasional damaged ones. Twenty beans were placed in a single layer in 6 × 6 cm shallow aluminum screen baskets. The

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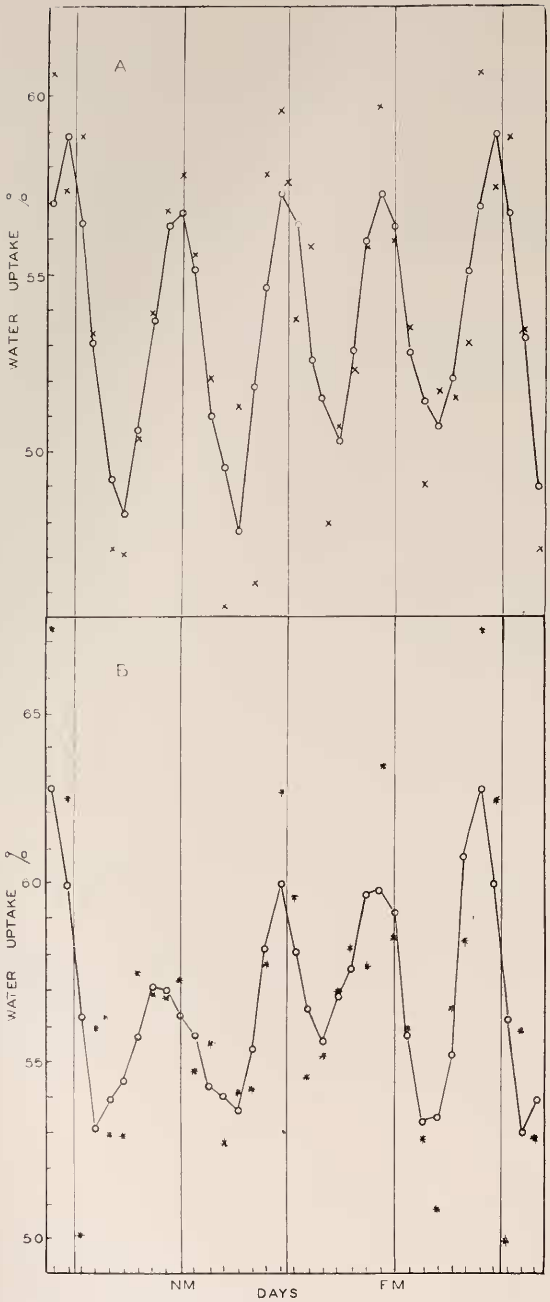

FIGURE 1(A). Mean synodic monthly variational pattern of 4-hour water uptake in Series A (June 27 through November 13, 1972), lines connect 3-day moving mean values; x's indicate individual-day points; (B) mean synodic monthly pattern of 4-hour water uptake in Series B over the same period of Figure 1(A). Symbols are as in Figure 1(A) except that asterisks replace x's.

TABLE 1

Series	Number of 20-bean groups	Calendar period	Days assayed	Results: figures	Mean range
Evanston, Illinois:					
A	12	June 27, 1972–Nov. 13, 1972	86	1A	16.8%
B	9	June 27, 1972–Nov. 13, 1972	91	1B	10.5%
C	16	May 15, 1972–Aug. 18, 1972	66	2A	11.8%
D	12	Sept. 25, 1972–Jan. 22, 1973	70	2B	10.7%
E	12	Sept. 25, 1972–Jan. 5, 1973	65	2C	13.5%
Woods Hole, Massachusetts:					
F	74	June 19, 1972–Aug. 22, 1972	46	3A	12.2%
Evanston, Illinois, Constant-temperature chambers:					
G	4	June 26, 1972–Aug. 24, 1972	41	3B	
H	4	July 26, 1972–Aug. 24, 1972	22	—	
I	4	July 17, 1972–Aug. 24, 1972	28	—	

dry weight of the 20-bean samples ranged typically between 7 and 9 grams. Usually 5 days a week baskets of beans were submerged in tap-water that had been allowed to stand in open containers at room temperature for 12 to 24 hours. One basket was submerged in water in each of 9 × 4.5 cm clear plastic cylindrical vessels. The basket of beans was removed immediately after submergence, pressed onto absorbent tissue, very rapidly weighed to nearest centigram on a torsion balance and resubmerged. After exactly four hours, always spanning the noon hour, the basket of beans was again subjected to same blotting and rapid weighing process. The difference between initial and final wet weights was taken to be the water absorbed. The weight of the absorbed water was expressed as a percentage of the initial dry weight and termed water uptake percentage.

EXPERIMENTS AND RESULTS

Synodic monthly variation in rate of water uptake

The existence of a lunar periodism in rate of water uptake was first noted during analysis of data obtained from two lines of six vessels of beans on a high wooden table in the center of a large laboratory room. The vessels were arranged to form a V with its two arms extending South and East. For this experimental series, A, assays had been made on 86 days distributed over an interval of 140 days (June 27 through Nov. 13, 1972). Correlation between the variations in daily means for the two 6-vessel groups was high, $r = +0.83$. When the 86 mean daily values for all 12 samples were examined in relation to elongation of moon (new moon ±7 days and full moon ±7 days), a quarter lunar variation was clearly apparent (Fig. 1A). Even for the 3-day moving means which were em-

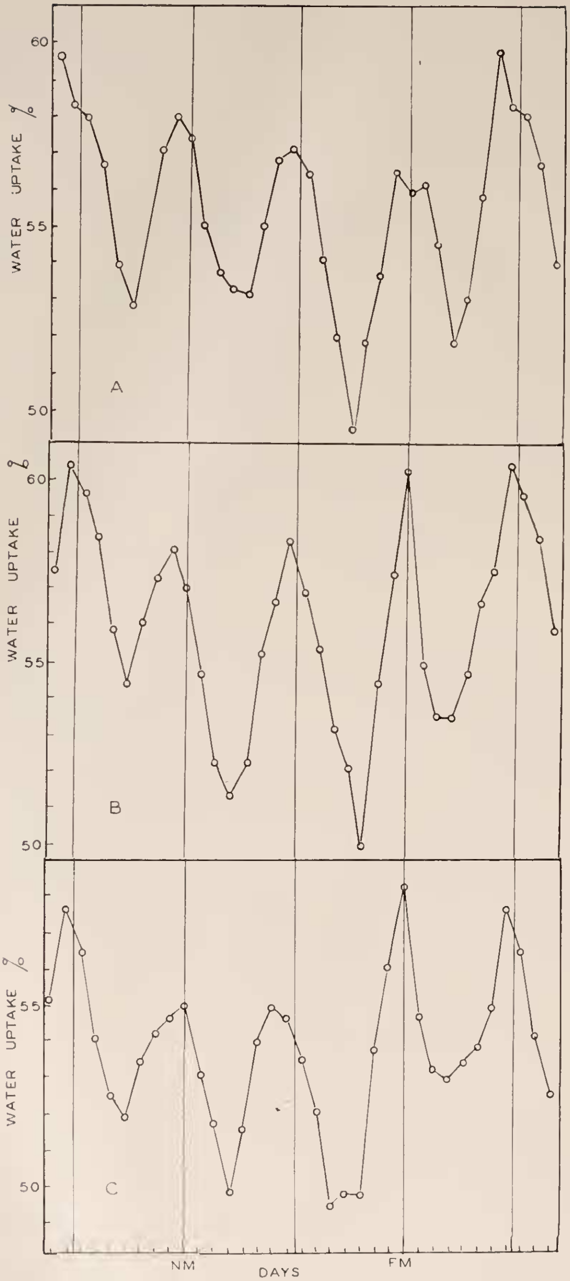

FIGURE 2(A). Mean synodic monthly pattern for Series C over period May 15 through August 18, 1972, (B) for Series D over period September 25, 1972 through January 22, 1973, and (C) for Series E for the period September 25, 1972 through January 5, 1973. All are three-day moving means.

ployed in recognization of the only approximate relationship between calendar day and moon phase and the many 2-day breaks in daily continuity of assays, the ranges of the mean cyclic variations were observed to be substantial, averaging 16.8% in increases from minima to maxima.

The data for beans in eight other experimental series were then examined. In Table I, these are described with regard to their number of 20-bean samples, span of calendar dates, number of days assayed, figure illustrating results, and mean percentage range of the quarterly cycles. Series A through E were on wooden tables in the open laboratory in Evanston, Illinois; Series F occupied wooden tables at the Marine Biological Laboratory, Woods Hole, Massachusetts, and Series G through I were in three different walk-in constant temperature chambers in Evanston. Despite use of beans from the same laboratory stock supply used in Evanston, the water-uptake rate in the Woods Hole laboratory was substantially higher and no reason was evident.

Series B comprised three triplets of linearly juxtaposed vessels with the three parallelling triplets 55 cm apart. Series D constituted three fully comparably arranged quadruplets. Series E involved six pairs of vessels equally spaced about the periphery of a clockwise rotating (2 rpm) 48-inch circular platform. Series C was one with 8 pairs of 20-bean samples. Two pairs were 50 cm from a slowly rotating (2 rpm clockwise from above) horizontal bar magnet which effected at the location of the beans a ±80° oscillation in a compass needle. Two more pairs, located 17 cm from the magnet were subjected to a periodic 360° rotation of the field at a horizontal vector strength substantially above the earth's natural one. Four other pairs at another laboratory location possessed exactly the same spatial arrangement but no magnet was present. The quarterly monthly variation appeared quite similar in both presence and absence of the rotating magnet and therefore the data for the 8 pairs were pooled.

Series F comprised the pooled results of a number of series including several geometric arrangements, speeds of slow clockwise and counter-clockwise rotation, and the weak field of a rotating magnet.

That conscious bias for lunar periodicity could not have contributed to the results was assured by two factors, (1) more than a dozen different laboratory assistants were involved in data gathering over the several series and (2), the experimental series were already completed, with other objectives in view, before the lunar relationship was discovered.

This demonstration by Figures 1A through 3A of a quarterly (average 7.4-day) lunar variation in bean water uptake, remaining phase-related to the moon's four quarters while encompassing a calendar span of 253 days and entailing 7931 20-bean measurements, leaves no reasonable doubt of a synodic monthly variation in water-uptake by the beans when investigated under these laboratory conditions. The precision in the continuing essentially same relationship to moon phase of the peaks and troughs in water uptake from beginning to end of the more than 8-month span clearly establishes the 7.4-day mean interval between the quarterly peaks as being distinct from any 7-day artifact. Even over the course of four of the presently described six series the quarterly lunar cycles essentially scanned completely the weekly periods. This relative lunar-phase stability of the mean periodism is especially remarkable in the face of a confounding contribution from interaction

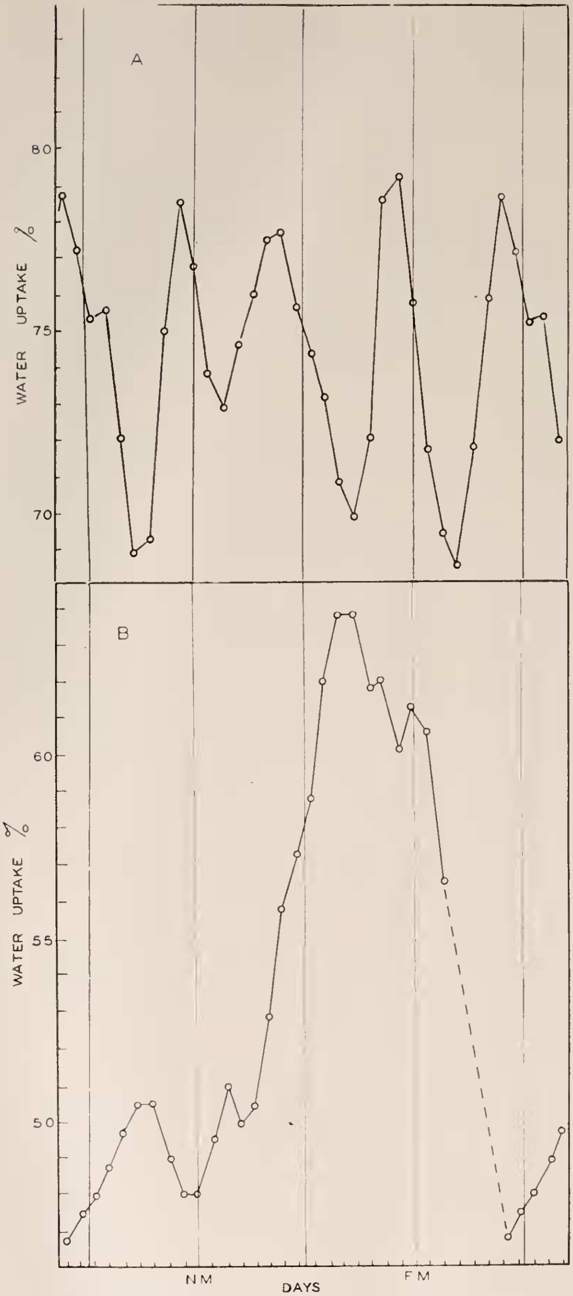

FIGURE 3(A). Mean synodic monthly pattern for bean water uptake for Series F during the period June 19 through August 22, 1972 at Woods Hole, Massachusetts, and (B) Series G in a constant-temperature chamber in Evanston, Illinois, for period June 26 through August 24, 1972. Both are three-day moving means. Broken line indicates gap in data.

between the 5-day-week assays and an apparent systematic semi-annual (minima, spring and fall) fluctuation occurring simultaneously in bean water uptake and emphasizes its polyphasal synodic monthly nature.

No suggestion is present that the period is an autonomous endogenous one for the beans, nor would such be expected in a biological system presumably as biochemically inactive (Bryant, 1972) as a dried bean seed assayed only during its first four hours in water. Instead, these mean cycles give every indication of being simply responses of the beans to lunar-controlled variations in some extremely weak and pervasive environmental parameters. Hence for the purpose at hand use of statistical procedures to determine detailed frequency of the observed variations seems superfluous. Far more valuable and potentially useful and predictable can be the demonstration of a moon-phase relationship.

When a lunar relationship was next sought for some bean series investigated under another, special laboratory condition, namely inside a temperature-controlled chamber, a striking difference was discovered. The earlier study (Brown and Chow, 1973) had described a strong negative correlation between simultaneous variation in water uptake inside (Series G) and just outside the chamber during the interval June 22 through August 4, 1972. Now, it was noted that under such conditions the quarterly lunar cycles also had been induced to exhibit a very conspicuous 180° phase shift.

Not only did minima instead of maxima occur at third quarter and new moon, but an epsecially high and broad maximum occurred between first quarter and full moon (Fig. 3B). Parallel but briefer studies (Series H and I) being conducted in two other constant-temperature chambers of identical type at other laboratory locations disclosed the same peculiar pattern having minima at third quarter and new moon and a very high maximum four days before full moon. Increases from the new moon mimimum to the high maximum for the three chambers were 33%, 41%, and 22%. For all three the duration of the rise and fall in rates in relation to this major maximum encompassed the days of first quarter and full moon.

Over the same calendar period of the foregoing odd patterns within the chambers, and using beans from the same laboratory stock, Series A in Evanston and Series F in Massachusetts were continuing to exhibit their typical quarterly variation. Series B, on the other hand, displayed for this period an inversion of its pattern over the time of new moon with a maximum 3 to 4 days before new moon and a minimum on the day of new moon; the remainder of the monthly pattern possessed its typical quarterly form. This inversion over new moon for this 64-day span within the total of 140 days accounted for the low range of the variation over new moon in Figure 1B.

Synodic monthly variation in interaction among bean samples

An effort was next made to learn whether or not the previously reported apparent interactions between bean samples close together in separate vessels also possibly possessed a lunar variation. Earlier evidence (Brown and Chow, 1973) had suggested that under some circumstances beans in closely apposed vessels mutually induced one another to adopt opposite signs of correlation with subtle geophysical variations, and under other circumstances the same sign. To learn how such alterable interactions might be fluctuating from one day to the next, possibly

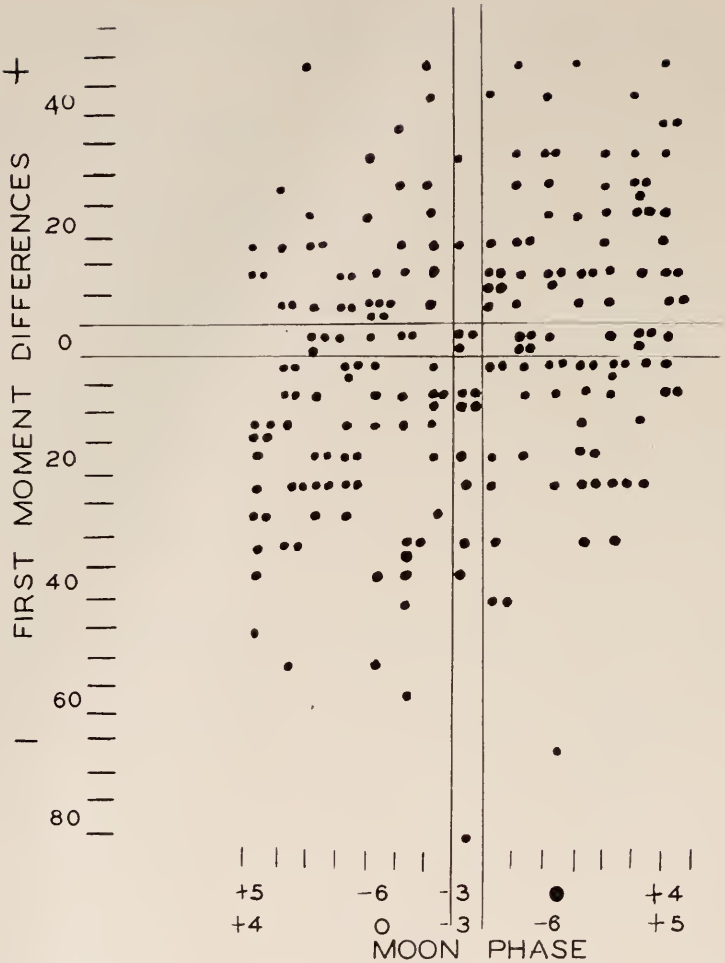

FIGURE 4. Scatterplot of the relationship between moon phase expressed as deviations in days from new moon and full moon and differences between first moment products of closely adjacent bean samples and comparable products of more remotely spaced samples. Included are the pooled results from four extensive experimental series (see text).

even involving a periodic lunar influence, the day-to-day first moments of deviations from their means for each of the several samples in each series were examined. Compared were the first moments, or products of the deviations, of adjacent pairs ("experimentals") and comparable first moments of an equal number of paired samples for which the two vessels were separated usually by 50 cm or more ("controls"). The day-to-day mean differences between first-moment values obtained for closely adjacent vessels and more remotely separated ones were determined. For this analysis, the data for "pairs" *vs* "singles" series previously described (Brown and Chow, 1973), the triplet series, the quadruplet series, and the V-one were used. For the latter three series first moments for alternate vessels in

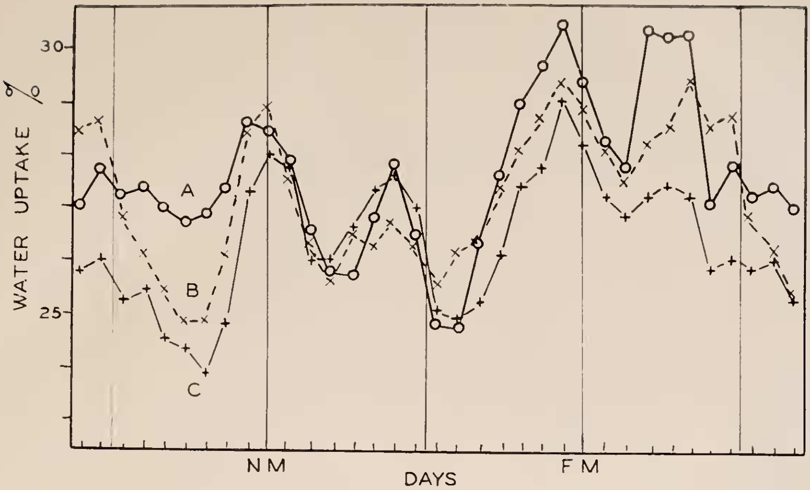

FIGURE 5. Synodic monthly patterns of variation in water uptake of beans over the period Jan. 23 through May 11, 1973 for three concurrent but independent experimental series; A., triplet series; B. quadruplet series; C., rotating magnet series.

a juxtaposed linear series were also determined and included in the pooled results since both the immediately adjacent and alternate vessels appeared to be within the interactional range.

For the "pairs" *vs.* "singles" data, "experimentals" were the three pairs and the "controls" comprised the six "singles." For the triplets and quadruplets the "controls" were the first moments between corresponding members in different ones of the three groups. For the V-series the "controls" were the first moments between members of the opposite groups of six, in reversed sequence.

Inspection of the day to day variation in first moment differences between the "experimentals" and "controls" in the same series suggested occurrence of a monthly variational behavior between vessels located close to one another. A maximum in a *negative* correlation between beans in vessels close to one another relative to concurrent "controls" appeared to occur 4 to 5 days following *new* moon and a maximum in *positive* correlation 4 to 5 days after *full* moon.

Figure 4 is a scatterplot of the relationship of the first moments of "experimentals" minus first moments of "controls" relative to moon phase. These include the mean values for each day of the synodic month for each the adjacents and alternates for all 4 series separately. The scatterplot appears to confirm that the dominant relationship involves greatest positive correlation 4 to 5 days after new moon and greatest negative 4 to 5 days after full moon. There is also suggested within the scatterplot the existence of a lesser inverted monthly relationship. Treating all the data for degree of linear correlation between moon phase and the first-moment differences, $r = +0.29$; $N = 210$; $t = 4.4$.

Experimental alteration of monthly patterns of variation

Additional explorations of the monthly water-uptake variations were made. Beginning January 23, 1973, pinto beans from a new 500-lb lot were used in several experimental series which terminated on May 11, 1973. The rate of water uptake for these beans was much lower despite continuation of the same environmental conditions as for the experiments described earlier. Using these new beans experimental series were carried out in an attempt to confirm the earlier results and to extend knowledge of properties of the phenomenon.

The triplet and quadruplet series were continued in exactly the same manner and places as for the earlier studies. An altered rotating magnet series was investigated. This latter comprised four pairs of vessels around the periphery of a circular table in the center of which a rotating horizontal bar magnet (2 rpm clockwise from above) was present on alternate days. The intervening days served as "controls" for possible influence of the experimental field. The strength of the imposed magnetic field was such as to effect about a ±80° oscillation in a compass needle at the sites of the beans.

In two other series, four pairs of vessels were equidistantly spaced around the edge of circular wooden tables 4 ft in diameter and rotating 2 rpm, one clockwise and the other counterclockwise.

A final two series involved four pairs of vessels (one member of a pair on top of the other) equidistantly spaced around the edge of rotating ($\frac{1}{3}$ rpm), 36-inch circular tables; one table rotated CW and the other CCW. These two series were carried out in a walk-in constant temperature room at 21.5° C, *i.e.*, about 1° lower than for the beans in the open laboratory.

Figure 5 describes the mean synodic monthly patterns of variation for the triplets, quadruplets, and magnetic-field series. For all three there was present a quarterly lunar variation of closely the same percentage range as described for the earlier studies. One difference, however, common to all three series, was an apparent few-day inversion of the quarterly pattern following the time of full moon.

For the series on the 2 rpm rotating tables being investigated in the same large laboratory room and indeed at a site about midway between the forementioned quadruplet and magnet series. The monthly patterns were not only quite evidently different (Figs. 6C and D) from the preceeding three, but differed slightly also between the clockwise (Fig. 6C) and counterclockwise (Fig. 6D) rotations. There is a suggestion that except for a high post-full moon maximum in common the two directional rotations tend to result in generally opposite phase relations.

The two series on the rotating platforms in the constant-temperaure chamber also appeared to display a very slight mirror-imaging tendency between CW (Fig. 6A) and CCW (Fig. 6B) rotations. However, there is a strong suggestion that for a given directional rotation, the beans within the constant-temperature chamber tend to mirror-image the comparable monthly pattern for the beans in the open laboratory outside the chamber. Compare Figures 6A and C, and 6B and D. This provides some confirmation for the odd monthly variations noted the previous summer within these constant-temperature chambers and described earlier.

Also noteworthy is that the water-uptake rate for all four rotating tables reaches essentially the same absolute rate when in apparently the same common phase relationship three to four days following full moon. When adopting a mirror-imaging relationship during most of the remainder of the month, however, the water-uptake rates tend to diverge. Particularly striking is the higher rate of water uptake inside the chamber despite the slightly lower temperature inside the tem-

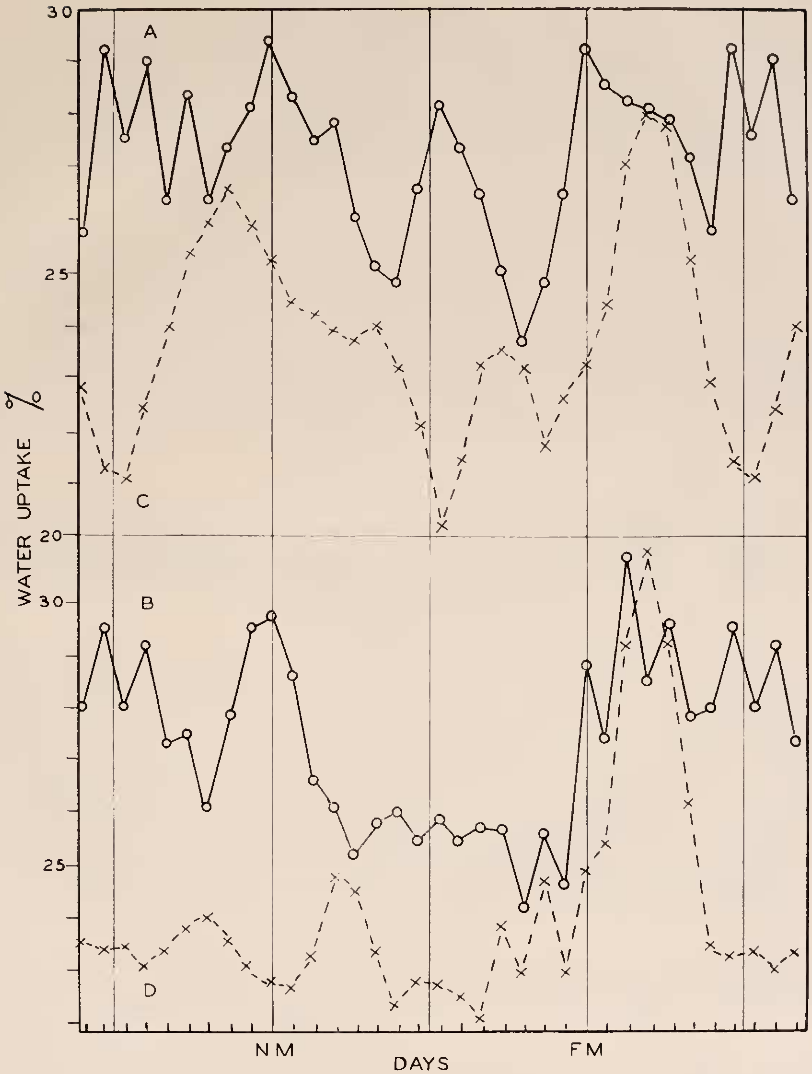

FIGURE 6(A and C). Mean monthly variation in water-uptake rates in beans on uniformly rotating platforms, clockwise from above: (A) at $\frac{1}{3}$ rpm inside a walk-in constant-temperature chamber at 21.5° C, and (C) in the general laboratory at 2 rpm and 22.5° C; (B) and (D) with fully parallel conditions to (A) and (C) except that the direction of platform rotation was counter-clockwise.

perature-controlled chamber than outside. This suggests that although the mean rate of water uptake is known to vary with temperature, for any given temperature the rate may differ between whether the sign of correlation with some biologically effective, pervasive, geophysical parameter or parameters is + or −.

Discussion

It seems probable that the effects reported here have been residual ones, algebraic summation of unbalanced positive and negative correlating relationships to the operating external parameters, and that the day-by-day effects themselves can be substantially greater. In fact, there has even been a great reduction in their real scope by the employment of the 3-day moving means (note the x's and asterisks in Fig. 1).

There were no differences in any obvious environmental factors responsible for the odd synodic monthly patterns within the temperature-controlled chambers. One is compelled to conclude, therefore, that the exact manner in which a biological system responds to a monthly variation in some subtle parameters of the atmosphere can be altered by other concurrent, ambient subtle-field states. Such an alteration can apparently be experimentally effected by such laboratory equipment as the temperature-controlled chambers and to a lesser extent by platform rotation. There is thus indication that some additional very weak physical parameters can determine the sign, + or −, of the response.

There is also clear suggestion from the present results that the concurrent character of ambient, subtle geophysical parameters can determine the character of the short-range, field interactions between adjacent organisms, in separate containers. These effective ambient-field differences can be as small as those associated with relative motions of earth and moon.

The presence of a quarterly lunar variation either alone, or concurrently with a larger unimodal or biomodal one has been evident in previously published results including responses to light in guppies (Lang, 1965, 1972) and planarians (Brown and Park, 1967a) and oxygen consumption and spontaneous motor activity of a variety of kinds of organisms (Brown, 1965). Indeed, in an unpublished full-year study in our laboratory a mean lunar quarterly variation in phototactic response in the flatworm *Dugesia*, superimposed on a larger-ranged unimodal component, has been confirmed during 1972–73. Minima in response occurred one to two days prior to the lunar quarters; the mean range from minima to maxima for the four mean cycles averaged 12.8% increase, strikingly of the same degree as for bean water uptake.

An apparent propensity for inversions of parts or whole of lunar cycles has been described (Brown, 1960, 1965). It seems reasonable to postulate, therefore, that existence of the quarterly lunar response component is widespread among both plants and animals. The potential for one or more of the quarterly components to undergo inversions in response to still undisclosed conditions has probably been responsible for the great difficulty experienced by previous investigators of lunar variations in organisms to repeat at will either their own results or those obtained by others. The current results, however, demonstrate a continuing, substantial periodic lunar influence upon a living system.

Described correlations of organismic variations with primary cosmic radiation (Brown, Webb and Bennett, 1958), with day-to-day geomagnetic fluctuations (Stutz, 1971), and with known geomagnetic mean cyclic patterns (Lang, 1972; Brown and Park, 1967b) suggest that the effective parameters providing the periodicities will be found within the electromagnetic family of forces. The evidence to date points to a probable simultaneous influence of several of their many parameters, and suggests that the ultimate solution will be neither quick nor simple.

These observations demonstrate that in what has been hitherto widely presumed to be fully equivalent environmental conditions there can be substantial rate differences. These differences appear to be accountable in terms of (1) a continuing organismic response to some subtle pervasive, and normally uncontrolled, geophysical variations and (2) the capacity of living systems to alter their sign of correlating state. Discovery of ways to regulate or modify these two response behaviors has potential practical applications, especially if the quarterly lunar influences and occurrence of + and − states prove to be as widespread as present indications now suggest and to include man himself.

In conclusion, the phenomenon of water uptake by such seeds as beans appears to provide one of the simplest of presently known means of investigating—in terms of organism, methods, and equipment—interactions of living systems with their subtle and pervasive geophysical environment, their characteristics, mechanisms, and roles.

The authors gratefully acknowledge the assistance of Mr. Jack S. Pierce in obtaining the data of series G, H and I.

Summary

1. Rate of water uptake by bean seeds during the initial four hours displays a significant quarterly lunar variation.

2. Under what appear to be minimally distrubed environmental conditions relative to environmental electromagnetic fields, maximum rates tend to occur close to new and full moon and the moon's quarters.

3. One or more of the quarterly cycles may undergo periods of inversion either apparently "spontaneously" or in response to such experimentally altered environmental conditions as those found within a walk-in constant-temperature chamber, or effected by very slow uniform rotation.

4. The character of an interaction between vessels of beans located close to one another displays a synodic monthly variation. A maximum in interaction-induced *negative* correlation between two samples occurs 4 to 5 days after full moon, and in *positive*, 4 to 5 days after new moon.

5. These results give further support for the hypothesis that living systems can exist in either of two states, + and − with respect to their correlation with fluctuating biologically effective and normally uncontrolled, pervasive geophysical parameters, and that this sign is experimentally alterable.

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